The Opposite Electrification produced by Animal and Vegetable Life.

By W. M. Thornton, D.Sc., D.Eng., Professor of Electrical Engineering in Armstrong College, Newcastle-upon-Tyne.

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1. *Introductory.*—When a steady electric current is passed through a drop of pond scum rich in animal and vegetable organisms, two opposite movements of migration of the living cells will in general be observed. Diatoms and unicellular algæ, for example, move towards the negative pole, amœboid animal organisms to the positive. The clearness of the effect is often confused by the presence of anchored and skeleton cells of either kind, and the case of pond scum is only given because the effect to be described was first observed in this way.

Early in 1904 it was desired to find an indicator for the qualitative detection of voltage gradient in liquids in fields of microscopic dimensions. The orientation of long diatoms into line with the current was anticipated from the known behaviour* of bacteria in an alternating field, and found to occur. In steady, that is unidirectional, fields they not only orientate but move along the line of current-flow to the negative pole. They therefore serve in two ways to indicate the presence of a steady current in the liquid.

At the first, and in all subsequent trials, the movement of migration of the diatoms was accompanied by one in the same direction of portions of most of the vegetable matter free to move, and a simultaneous movement in the reverse direction of the free animal forms, provided that the motile activity of the latter did not overpower the mechanical influence of the field. The movement was quite dead-beat, reversing instantly with the reversal of polarity, and since the only mechanical force an electric field can exert is upon an electric charge it was concluded that the opposite movement of the cells indicated that they carried opposite charges, the animal cells being negatively electrified, the vegetable cells positively.

2. *Method of Experiment.*—To observe the movement it is well to have the field as strong as possible; it was found that 75 volts per centimetre was the highest which could be conveniently used. This is much greater than that employed by previous workers, which rarely exceeded 10 volts per centimetre.

To avoid trouble by liberation of gas at the electrodes with this high

* L. Lortet, 'Comptes Rendus,' April 20, 1896, p. 892.

gradient it is necessary to use a small current, that is to have a high resistance between the poles, such as one obtains from a thin film of liquid of high resistivity, 300 to 1000 ohms per centimetre cube.

The method used was to place a drop of tap water, weak saline or cane sugar solution, on a glass slide, to introduce by a platinum needle the cells to be observed, and to place a $\frac{3}{4}$-inch square cover slip over it. The drop was just sufficient to fill the space below the slip without flooding it.

The electrical pressure was then applied from a hand generator of the kind used in testing the insulation of electric cables, giving about 150 volts when turned slowly, 500 volts quickly, on open circuit. The pressure from a direct-current electric lighting supply with a water resistance or bank of lamps in series also serves well. The current strength should be such that bubbles form at the electrodes very slowly or not at all. The current was led into the drop by means of two fine platinum wires secured to an insulating cross-bar by wax, and attached by flexible wires to a reversing key and the generator. The bar could be raised or lowered freely. The stand holding it was of such a height that the wires were almost horizontal, lying along opposite sides of the cover slip. Using a $\frac{1}{12}$-inch oil-immersion lens the cells crossed the field in a few seconds when the generator was turned slowly.

It is difficult when working with bacteria to avoid the influence of streaming under the slip caused by change of capillarity through electrification, and it is only by repeated trial that the exact thickness of liquid for dead-beat movement can be obtained. With blood and yeast cells, however, the electro-mechanical force on the cell is much greater, and streaming gives less trouble. Its occurrence can in any case be readily seen by the organisms continuing to move after the stoppage of the current.

Before dealing with living cells it must be stated that almost all finely divided matter can be made to migrate in an electric field in suitable liquids. This has been very fully investigated, notably by Quincke,* Hardy,† Perrin,‡ and Burton.§

The present results are differentiated from these by the clear division between the movement of the two types of life, in general irrespective of habitat, culture medium or composition of the cell, provided that this is fresh. The intensity of the movement is conditioned largely by the relative conductivities of the organisms and the surrounding liquid.

* Wiedemann, 'Electricität,' vol. 2, pp. 166 *et seq.*

† W. B. Hardy, 'Roy. Soc. Proc.,' B, 1900, vol. 66, p. 110.

‡ Jean Perrin, 'Journ. de Chim. Physique,' 1904, vol. 11, 10, p. 607.

§ C. V. Burton, 'Phil. Mag.,' April and November, 1906.

In repeating the experiments the chief difficulties will be found to be (1) in maintaining electrical contact between the wires and the drop without excess of liquid; (2) in the cells adhering to the slide and cover slip; (3) in distinguishing between forced movement of the cells and free movement due to streaming. Whenever there is no movement either the electrical circuit is broken or the cells are anchored. To avoid the disturbing influence of ions from the poles the current should be reversed every five to ten seconds of continued observation.

The essential points are fresh cells, neutral liquid, high voltage and resistance; in addition to which the electrical conductivity of the liquid should be less than that of the organisms. The reason for the latter is that when it is greater the current avoids the cell, preferring to go by the liquid. On the other hand, when the conductivity of the organism is greater the current converges upon it.

3. *Infusoria.*—From time to time attempts were made to obtain conditions under which the effect could be demonstrated with certainty. Motility of any kind gave trouble; thus *Paramœcium* was found by Verworn* to move to the negative pole; but if the current is switched on while clusters of the organisms are under observation, they will be found almost without exception to burst towards the positive. This was also observed by Verworn. *Euglena*, again, bursts towards the positive. The cell contents of Rotifers and of small fresh-water worms move towards the positive, the sacs clearing on the negative side. Many similar observations were made, but the results were, as a rule, not sufficiently marked or uniform for repeated demonstration. These were all with cells in their natural habitat. Dale,† by a careful examination of the movement of parasitic infusoria in various solutions, arrived at the following results. The reaction of the host—a frog—was always alkaline. In an alkalinated solution *Opalina ranarum* moved to the positive (p. 310); *Nyctotherus cordiformis* from a freshly killed frog to the positive (p. 316); *Balantidium entozoon*, alkaline, in strong currents to the positive, then later to the negative (p. 321); *Balantidium elongatum* (p. 326), and *Balantidium duodeni* (p. 332), first to the positive and after some hours to the negative. It is not stated whether the organisms were then found to be living, but is of interest to note that the movement, whilst they were fresh, was in each case to the positive. The reversal may be compared with that of plants given in the next section. In acid solutions the movements were in general reversed, but the

* 'Psycho-physiologische Protistenstudien,' Jena, 1889.

† H. H. Dale, 'Journ. of Physiology,' vol. 26, pp. 219 *et seq.*

conditions are then not those of normal life or growth, since the reaction of the fresh frog was alkaline.

Starting from Hardy's conclusion (*loc. cit.*) that acid particles are electrically negative and basic particles positive, Lillie* investigated the movement of certain animal cells. He found that the red corpuscles and smaller leucocytes—in frog's blood—move to the positive, the voluminous leucocytes to the negative. With spermatozoa there is active migration of the sperm head to the positive, the tail having been absorbed in the cane sugar solution used. With teased-out tissue the effect was not so certain, which he suggests may be the result of *post-mortem* alteration of muscle substance, and of the injury in teasing out the cells. His conclusions are "that the direction and speed of electrical migration of living cells and portions of tissue are chiefly dependent upon the electrical characteristics of their constitutent colloids, that animal cell nuclei exhibit a strong tendency to migrate to the positive pole, and that this is strongest in those nuclei in which the proportion of nucleic acid is highest."

Perrin (*loc. cit.*), discussing colloidal solutions, observes that "a charge which is raised by the presence in the solvent of a monovalent acid is lowered by a monovalent base," an extension of Hardy's conclusion. Jennings'† paper on "The Reactions of Electricity in Unicellular Organisms" is a criticism of others by Birnkoff and Greely on the migrations of infusoria, chiefly *Paramœcium*. Greely states that, in his opinion, "the electrical condition of the protoplasm itself determines the motion."

4. *Vegetable Cells.*—In the present experiments the first clear movement of vegetable matter observed, other than that of diatoms, was of filaments of *Vaucheria*, which moved to the negative. *Volvox aureus* moved and burst to the negative, as was also observed by Carlgren.‡ *Sphœrella plantaginis*, a pleurococcus (chlorophyll green alga), a unicellular alga, and protococci from moist growths, all moved to the negative. Working by the method described, the following bacteria, when taken from young active growths and examined immediately, moved without exception to the negative:—*B. typhosus*, *B. tuberculosis*, *B. diphth. avium*, *B. prodigiosus*, B. Lactic acid, *B. pyocyaneus*, *B. coli comm.*, *B. Friedländer*, *Sarcina aurantiaca*, *Sarcina lutea*, *Staph. aureus*, Spore-bearing bacillus, Hog cholera, Pneumococcus. Bacteria from cultures which had been standing in the laboratory for some time and were not sub-cultured before being examined, and bacteria which, though sub-cultured 24 hours before use, showed very poor growth, almost invariably moved to

* R. S. Lillie, 'Am. Journ. of Physiol.,' 1903, vol. 8, p. 276.

† H. S. Jennings, 'Journ. Neurology and Psychol.,' 1905, pp. 528—534.

‡ Archiv f. Anat. a. Physiol.,' Physiol. Abth., 1900, p. 49.

the positive. This reversal is no doubt accompanied by marked changes in the protoplasm. In the case of an unclassified non-motile bacillus, in the laboratory of the University of Durham College of Medicine, isolated from a scarlet fever patient, a most active migration to the negative was obtained, which, tested by samples from the same agar tube kept after incubation in a cool place, lasted for about ten days, when it reversed. No further observations were possible on this organism because it soon after died out.

Russ,* working with weak voltage gradients, small currents and many hours' exposure, has recently found some bacteria to migrate to the positive pole, others to the negative. In view of the present experiments the former may be attributed to either motile response to stimulus, or the forced movement of organisms of which the charge had been reversed by prolonged action of the solution.

With regard to the movement of growing plants, Brunchhorst† found that roots extending into water through which a moderate current was passed bent towards the negative, but when the current was strong to the positive. He regarded the latter effect as secondary and due to electrolytic action. Ewart and Bayliss‡ regard it as stimulatory. They apparently agree that, with moderate currents, the movement to the negative is a response to stimulation. Jost§ notes that "roots which in the strong current exhibit positive curvature always die, not only on the positive side but altogether, at the latest after 24 hours. The negative curvature appears to be genuine stimulation, with the root apex acting as the organ of perception." Letellier|| also observed curvature of growing roots towards the negative pole. The sporangiophore of *Phycomyces* was found by Hegler¶ to bend towards the negative pole under the influence of Hertzian radiation.

From the difficulty experienced in working with motile organisms it was decided that although there was cumulative evidence that the difference between the animal and vegetable reaction was real, a crucial test could only be made with non-motile cells of either kind, the animal cells fresh from the animal, the vegetable cells from an active growth.

5. *Blood Corpuscles and Yeast.*—Human blood corpuscles satisfy the conditions in every way. They are readily obtained fresh and, containing a high percentage of salts, are not too sensitive to external influences. At first it

* C. Russ, 'Roy. Soc. Proc.,' 1909, vol. 81, p. 314.

† 'Ber. d. bot. Ges.,' 1884, p. 207.

‡ 'Roy. Soc. Proc.,' B, 1905, vol. 77, p. 63.

§ 'Plant Physiology' (trans. Harvey Gibson), 1907, p. 481.

|| 'Bull. de la Soc. bot. de France,' 1899, vol. 6, p. 11.

¶ 'Verhandlg. d. Ges. deutscher Naturf. Aerzte in Halle,' 1891.

was thought that bacteria could be found to satisfy the conditions equally well, in spite of the difficulty of observing them readily, but in any loopful there are liable to be inert organisms which confuse the result. Many observations were, however, made with blood corpuscles and bacteria mixed in a drop of tap water or weak saline solution. When the latter were fresh the effect was marked, the blood cells of both kinds moving actively to the positive, the bacteria to the negative, streaming past one another, stopping, starting, and reversing with the current.

For the purpose of demonstration the difficulty was to find a vegetable growth of great vigour with single non-motile cells of convenient size for observation. This was eventually found in *Torula*. Yeast is easily obtained and complies with all the requirements. Blood and yeast cells are of the same size, but the slight colour of the former and the oval shape of the latter enable them to be readily distinguished. Judging by the velocity of migration the charge carried is of the same order in each. In a field containing many of both kinds they move past each other and after collision pass on with unchanged speed. The effect can be readily projected upon a screen with arc light, using a No. 6 objective well stopped down, the disc obtained being about 3 inches in diameter. It is unlikely that the electrical charges reside only on the surface, for they would, at least in part, coalesce, as they do in neutralised colloidal solutions.* The charges of blood and yeast cells appear also to be exceedingly stable. Smears of either on glass, dried for several days, on being moistened with water exhibit the effect quite well.

It may then be reasonably concluded, in so far as it is possible to have a single crucial test for so wide a range of activities, that fresh animal cells are negatively, and vegetable cells positively electrified. The fact that collisions do not discharge the cells, and that in both kinds the reversal of charge (which has no doubt led to most of the conflicting evidence on electrical migration of cells) takes place slowly, and cannot well be located in the cell wall, suggests that the above conclusion may tentatively be extended to the protoplasm. The principal difference between the two modes of life would then be that active animal protoplasm produces negative electrification, vegetable positive. Expressed in terms of Hardy's results the former is acidic, the latter basic in type.

6. *Contributory Evidence.*—This conclusion is not without support from less direct experiment. It has been shown by Dr. Waller† that the local skin response current is opposite in sign in animal and vegetable tissues, indicating an essential difference in the normal charge of their cells.

* W. B. Hardy, *loc. cit.*

† A. D. Waller, 'Signs of Life,' p. 84, § 51.

From experiments on the action of static charge on growing plants Lemström* found that air positively ionised stimulated growth much more than when the charge was negative.

These observations agree with the view that there is an essential difference in sign between animal and vegetable charge, that of vegetable growth being positive.

If then a supply of negatively charged matter raises the activity of animal protoplasm and depresses that of bacteria, it may be even possible in disease to stimulate the blood directly by the inhalation of negatively charged air. It is worth examining where in nature air is found to have a free negative charge. Elster and Geitel† have shown that at high altitudes there is always a much stronger discharge of negative than of positive electrification. The action of sunlight, especially of the ultra-violet rays, is to cause a leak of negative charge from growing leaves and from pine trees in particular, the latter no doubt in part from the discharging influence of sharp points. The presence of negative charge in high pine woods from a combination of these causes may account in some measure for their marked curative properties, in tuberculous disease of the lung for example. In view of the difficulty of attacking tubercle *in situ* and the importance of the desired result, the suggestion is offered that the inhalation of air charged artificially with negative ions might prove useful in the treatment of tubercle of the lung, either by raising locally the activity of the blood cells or lowering that of the organisms.

It may be remarked that nascent oxygen and chlorine, which in electrolysis carry a strong negative charge, are active bactericides, hydrogen, the only electropositive gas, is not.

7. *Classification of Rudimentary Organisms.*—When the cells are fresh or active the described effect provides a sensitive means of distinguishing between animal and vegetable. Thus *Lycogala* (Mycetozoa) moved to the positive pole and was thus, in the specimens examined, animal in type. Resting spores of *Badhemia utricularis*, after several hours in water, moved equally well to the negative pole, as vegetable. Whether the latter observation is an example of the reversal of sign of an animal cell, similar to that constantly found with bacteria, or an indication that the organism may possibly be vegetable in type, requires further examination. Mr. J. J. Lister‡ observes that "*Badhemia utricularis* is exceptional in feeding on living fungi, though it will also live and thrive on the same fungi after they have

* S. Lemström, 'Electricity in Agriculture,' 1904, p. 62.

† 'Ann. d. Physik,' 1900, vol. 2, p. 425.

‡ 'A Treatise on Zoology' (ed. Sir E. Ray Lankester), "The Protozoa," p. 49.

become dried, if they are wetted again with water." It also differs from many Mycetozoa in growing in strong sunlight.*

It would be of interest to examine in this way the rudimentary organisms which at present occupy an undefined position between the two great divisions of living matter. If protoplasm is identically the same in animal and vegetable cells the principle of life for each must be the power of determining its activity so that as a result the charge of one becomes negative and the other positive. It is also possible that the protoplasm itself may not be the same, and that the characteristic electrical charge is obtained not by separation within the cell but by selective absorption from without, so that the protoplasmic cell-content cannot be regarded as quite the same in the two cases.

In conclusion I wish to express my indebtedness to my colleague, Prof. H. J. Hutchens, for most useful advice.

The Fermentation of Galactose by Yeast and Yeast-juice. (Preliminary Communication.)

By Arthur Harden, F.R.S., and Roland V. Norris.

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Numerous investigators have shown that many species of yeast which ordinarily do not ferment galactose, readily acquire that property when cultivated in a medium containing that sugar.

The present communication briefly describes experiments which have been made with living yeast in this way, and with the juice obtained from this yeast. Experiments are also proceeding with yeast "killed" by acetone and other reagents (zymin), and it is hoped when these are complete to give a more detailed account of the whole investigation in a future paper.

Pure cultures of S. Carlsberg I have been used throughout these experiments. The medium employed for "training" the yeast consisted of yeast water to which was added 20 per cent. of hydrolysed lactose and 0·15 per cent. of K_2HPO_4.

* *Loc. cit.*, p. 48.